99B-138

UNIVERSITY OF CALIFORNIA, SANTA BARBARA

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OFFICE OF RESEARCH   SANTA BARBARA, CALIFORNIA 93106-2050

Record Number: 08991163
April 15, 1999

CALFED Bay-Delta Program Office
1416 Ninth Street
Suite 1155
Sacramento, Ca 95814

Presented for your review is a request for support of the following described project:

TITLE: Modeling the Influence of Restoration Scenarios on Channel and Floodplain Morphology in the Sacramento River Basis

PRINCIPAL INVESTIGATOR (S): Dr. T. Dunne

ADMINISTERING UNIT: Bren School of Environmental Science and Management

TYPE OF PROJECT: New

PREVIOUS AWARD NUMBER:

SUPPORT REQUESTED: $408,409

PERIOD REQUESTED: 10/01/99 – 09/30/02
We have had the opportunity to review the anticipated terms and conditions of awards listed in attachment D and have found some to be inconsistent with University policy. Therefore, if the proposal is accepted for award, the University intends to take exception to some of the terms and conditions per my conversation today with Rebecca Fawver.

Additional program information can be obtained from the Principal Investigator. All other inquiries should be directed to the undersigned at the letterhead address.

Your favorable consideration of this request will be appreciated. Should the project be approved, the award should be issued in the name of The Regents of the University of California, c/o the Office of Research, University of California, Santa Barbara, CA 93106-2050.

Sincerely,

Dorothy C Hall

Dorothy C. Hall
Sponsored Projects Officer
(805) 893-4034

DCH: mc
Enclosures
cc: Principal Investigator
Department Liaison

UCSB/OR Form 101 (Rev. 3/92)

99B-138

Cover Sheet (Page 1 of 2)

Proposal Title:	Modeling the Influence of Restoration Scenarios on Channel and Floodplain Morphology in the Sacramento River Basin
Applicants Name:	The Regents of the University of California, Santa Barbara
Mailing Address:	Office of Research University of California Santa Barbara, CA, 93106
Telephone:	805-893-7557
Fax:	805-893-7612

Amount of funding requested: $ 408,409 for 3 years.

Indicate the Topic for which your applying (check only one box)

- ☐ Fish Passage/Fish Screens
- ☒ Habitat Restoration
- ☐ Local Watershed Stewardship
- ☐ Water Quality
- ☐ Introduced Species
- ☐ Fish Management/Hatchery
- ☐ Environmental Education

Does the proposal address a specified Focused Action? X yes ______ no

What county or counties is the project located in? Shasta, Tehama, Glenn, Butte, Colusa, Sutter, Yolo, Sacramento and Solano

Indicate the geographic area of your proposal (check only one box):

- ☒ Sacramento River Mainstem
- ☐ Sacramento Trib: ____________
- ☐ San Joaquin River Mainstem
- ☐ San Joaquin Trib: ____________
- ☐ Delta: ____________
- ☐ East Side Trib: ____________
- ☐ Suisun Marsh and Bay
- ☐ North Bay/South Bay: ________
- ☐ Landscape (entire Bay-Delta watershed)
- ☐ Other: ________

Indicate the primary species which the proposal addresses (check all that apply):

- ☐ San Joaquin and East-side Delta tributaries fall-run chinook salmon
- ☒ Winter-Run chinook salmon
- ☒ Late-fall run chinook salmon
- ☐ Delta smelt
- ☒ Splittail
- ☒ Green sturgeon
- ☐ Migratory birds
- ☐ Other: ____________
- ☒ Spring-run chinook salmon
- ☒ Fall-run chinook salmon
- ☐ Longfin smelt
- ☒ Steelhead trout
- ☒ Striped bass
- ☒ All chinook species
- ☒ All anadromous salmonoids

Specify the ERP strategic objective and target(s) that the project addresses. Include page numbers from January 1999 version of ERP volume I and II:

Rehabilitation of Natural Processes, ERP I, p. 42-43 and ERP II, p.l.

Indicate the type of applicant (check only one box)

- ☐ State Agency
- ☐ Public/Non-profit joint venture
- ☐ Local government/district
- ☒ University
- ☐ Federal agency
- ☐ Non-profit
- ☐ Private party
- ☐ Other: ______________

Indicate the type of project (check only one box):

- ☐ Planning
- ☐ Monitoring
- ☒ Research
- ☐ Implementation
- ☐ Education

By signing below, the applicant declares the following:

1.) The truthfulness of all representations in their proposal;

2.) The individual signing the form is entitled to submit the application on behalf of the applicant (if the applicant is an entity or organization): and

3.) The person submitting the application has read and understood the conflict of interest and confidentiality discussion in the PSP (Section 2.4) and waives any and all rights to privacy and confidentiality of the proposal on behalf of the applicant, to the extent as provided in the Section.

Dorothy C Hall

Dorothy C. Hall
Sponsored Projects Officer

Thomas Dunne

Thomas Dunne

OMB Approval No. 0348-0043

APPLICATION FOR FEDERAL ASSISTANCE

2. DATE SUBMITTED 4/16/99

Applicant Identifier

1. TYPE OF SUBMISSION:

Application
- [ ] Construction
- [x] Non-Construction

Preapplication
- [ ] Construction
- [ ] Non-Construction

3. DATE RECEIVED BY STATE

State Application Identifier SAI Exempt

4. DATE RECEIVED BY FEDERAL AGENCY

Federal Identifier

5. APPLICANT INFORMATION

Legal Name: Regents of the University of California

Organizational Unit: Office of Research

Address (*give city, county, State, and zip code*):
Office of Research
Santa Barbara, CA 93106

Name and telephone number of person to be contacted on matters involving this application (*give area code*)
PI: Thomas Dunne 805-893-7557
Admin: Dorothy C. Hall 805-893-4034

6. EMPLOYER IDENTIFICATION NUMBER (*EIN*): 95-6006145

7. TYPE OF APPLICANT: (*enter appropriate letter in box*) I

A. State
B. County
C. Municipal
D. Township
E. Interstate
F. Intermunicipal
G. Special District
H. Independent School Dist.
I. State Controlled Institution of Higher Learning
J. Private University
K. Indian Tribe
L. Individual
M. Profit Organization
N. Other (Specify) ____________

8. TYPE OF APPLICATION:

- [x] New
- [ ] Continuation
- [ ] Revision

If Revision, enter appropriate letter(s) in box(es) [ ] [ ]

A. Increase Award B. Decrease Award C. Increase Duration
D. Decrease Duration Other(*specify*):

9. NAME OF FEDERAL AGENCY: Department of the Interior

10. CATALOG OF FEDERAL DOMESTIC ASSISTANCE NUMBER: 15-614

TITLE: Coastal Wetland Planning Protection & Restoration

11. DESCRIPTIVE TITLE OF APPLICANT'S PROJECT:
Modeling the Influence of Restoration Scenarios on Channel and Floodplain Morphology in the Sacramento River Basin

12. AREAS AFFECTED BY PROJECT (*Cities, Counties, States, etc.*):
Sacramento River Mainstem

13. PROPOSED PROJECT

Start Date	Ending Date
10/1/99	9/30/02

14. CONGRESSIONAL DISTRICTS OF:

a. Applicant: 22

b. Project: 2

15. ESTIMATED FUNDING:

a. Federal	$ 408,409	.00
b. Applicant	$	.00
c. State	$ 0	.00
d. Local	$ 0	.00
e. Other	$ 0	.00
f. Program Income	$ 0	.00
g. TOTAL	$ 408,409	.00

16. IS APPLICATION SUBJECT TO REVIEW BY STATE EXECUTIVE ORDER 12372 PROCESS?

a. YES. THIS PREAPPLICATION/APPLICATION WAS MADE AVAILABLE TO THE STATE EXECUTIVE ORDER 12372 PROCESS FOR REVIEW ON:

DATE April 15, 1999

b. No. [ ] PROGRAM IS NOT COVERED BY E. O. 12372
[ ] OR PROGRAM HAS NOT BEEN SELECTED BY STATE FOR REVIEW

17. IS THE APPLICANT DELINQUENT ON ANY FEDERAL DEBT?

- [ ] Yes If "Yes," attach an explanation.
- [x] No

18. TO THE BEST OF MY KNOWLEDGE AND BELIEF, ALL DATA IN THIS APPLICATION/PREAPPLICATION ARE TRUE AND CORRECT, THE DOCUMENT HAS BEEN DULY AUTHORIZED BY THE GOVERNING BODY OF THE APPLICANT AND THE APPLICANT WILL COMPLY WITH THE ATTACHED ASSURANCES IF THE ASSISTANCE IS AWARDED.

a. Type Name of Authorized Representative: Dorothy C. Hall

b. Title: Sponsored Projects Officer

c. Telephone Number: 805-893-4034

d. Signature of Authorized Representative: Dorothy C Hall

e. Date Signed: 4/15/99

Modeling the Influence of Restoration Scenarios on Channel and Floodplain Morphology in the Sacramento River Basin

Investigators: **Thomas Dunne,** Professor
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Institution: Donald Bren School of Environmental Science & Management, University of California, Santa Barbara

Type of Organization: University
Tax Status: Non-Profit
Tax ID #: 93-6006145

Project Period: October 1, 1999—September 30, 2002

I-014880

Modeling the Influence of Restoration Scenarios on Channel and Floodplain Morphology in the Sacramento River Basin

EXECUTIVE SUMMARY

Riparian habitats are defined by configurations of stored sediment that define channel and floodplain morphology. This topographic complexity in the riparian corridor depends on hydrology, sediment transport, boundary conditions, and history of channel change. In order to aid in habitat restoration efforts we propose to research the influence of these factors on river channel and floodplain morphology in the Sacramento River valley. We will investigate the relative effects of the following Ecosystem Restoration Program (ERP) restoration strategies on channel and floodplain evolution: streamflow alterations, changes in sediment supply, and channel modifications. We will develop a predictive model for decision-makers attempting to approximate the "natural" and other potential states of the river system under different restoration scenarios.

Scope of Work

The CALFED ERP document [*ERP*, Vol.1, p.42-43] states the intention of manipulating flows, sediment supplies, and boundary conditions (e.g. levees) in order to alter the form and hydrologic regime of channels and near-channel wetlands. Yet there is no available model of morphological process that would allow predictions of such responses to be made for long reaches of mainstem rivers, and of how a change in any of the manipulated factors would be expected to influence habitat conditions.

We propose to construct a mathematical model of sediment routing in the channel and floodplain of the mainstem Sacramento River that would provide the predictive capability necessary for analyzing management alternatives. It will be our goal to model the manipulable and the uncontrollable influences on the sediment budget and their consequences for habitat creation and evolution.

Research Questions

As CALFED embarks upon a program of significant riparian-zone management, it becomes important to understand the fluxes which govern channel and floodplain morphology. We would utilize this opportunity to investigate the following questions. How have sediment and hydrologic flux varied in the past and what were the resulting morphological changes? How will restoration measures involving flow modification, changes in sediment supply, and channel alteration affect channel and floodplain morphology? How will changes in local channel and floodplain morphology affect the evolution of "restored" valley floors?

Approach

Our approach involves compilation and interpretation of sediment transport and assimilation of these data into a model for prediction and analysis of future scenarios. We are currently working to quantify empirical relationships between fluxes of water and sediment, channel and floodplain forming processes, and resultant form of river channels and floodplains within the Sacramento basin. These historical relationships will be used to develop a river adjustment model, which will be validated against separately-collected empirical data. There exists a long historical record of measurements of sediment concentration and streamflow throughout the basin and a long historical record of perturbations to the system. Yet, there are no comprehensive, quantitative process studies of hydrology and sediment transport as they relate to resultant channel changes in the Sacramento basin. Our aim is to construct a supply-process-form model with a minimum amount of calibration that could be applied to any large lowland river system to predict river adjustment under different land-use scenarios.

To develop this model we will evaluate the sediment mass balance of the Sacramento River basin to gain insight into the fluvial processes of the river system and to identify areas of morphological adjustment. This empirical investigation will provide relationships to be used as supply inputs for modeling sediment routing and long-term average sediment transport rates with which to validate our model. Since a large lowland river basin such as the Sacramento has sediment transport processes that operate on different spatial scales, we will develop a stochastic model with two spatial components: a **basin-scale** sediment routing component coupled with a **reach-scale** routing component. Model output

will predict reach-scale channel and floodplain morphology in the form of probabilities. For example, a change in sediment supply stemming from a particular management strategy could be modeled to obtain model results in the form of probabilistic statements about a particular reach of river being in a particular state. Thus habitat and flood control strategies can be prioritized based on the model's output. We have already begun some of this work with the resources supplied by UC Santa Barbara, and with data and advice from the Army Corps of Engineers and US Geological Survey.

Ecological Objectives

The ERP [*ERP,* Vol.1, p.29] suggests that prospective lands be identified and designated for particular target species habitat restoration. However, identifying, classifying, acquiring, and slating lands for restoration based on current states of physical form can belie transient states of a system [*Chang*, 1988; *Kondolf*, 1995b]. It is qualitatively well known that morphological change results from imbalances between erosion and deposition. However, in order to understand and predict the circumstances under which large-scale flooding will occur or specific habitat will be affected, it is necessary to obtain a system-wide perspective of a river basin and to gather information on the variable processes of material transport within a river. For example, desired backwater channel habitat for a particular target species may only exist during floods of a certain magnitude or in an area and time of sediment deposition. Determinations of suitable habitat founded on rudimentary land classification without knowledge of processes which create the form often lead to failure of the restoration effort [*Kondolf*, 1995b]. In the Sacramento River basin, we see the opportunity for a study which would model the processes and variability inherent in a large river valley at the appropriate scales of interest and thus provide the underpinnings for a systematic approach to present and future restoration activities.

Such a model could be used by CALFED to target restoration policy by identifying which restorative strategies are appropriate for different reaches in the basin. By quantifying change in morphology and flood conveyance capacity, it would allow CALFED to strike a balance between seemingly opposing goals of flood control and habitat restoration. As such, our model would provide a unifying restoration framework upon which the various CALFED agencies could achieve stated ERP goals in synchronicity and with complementary strategies. In focusing attention and understanding on reaches that undergo morphological change, the modeling effort would interface with higher-resolution modeling studies of channel shifting (Larsen and Mount, UC Davis) and with field measurement programs of bedform transport and channel change [*Dinehart*, pers. comm]. Such collaboration of sediment accounting and modeling studies across scales could unify understanding of basin-scale and within-reach scale processes of sedimentation and habitat change in the Sacramento River basin. We have already confirmed such a model's usefulness with the US Geological Survey Water Resources Division-Sacramento and the US Army Corps of Engineers-Sacramento.

Qualifications

We have experience with large rivers, system perturbations, and sediment variability models. Dunne and colleagues have conducted a study of the channel-floodplain sediment budget of a 2500 km reach of the Amazon River and the associated geological and hydrological controls and morphological results [*Dunne et al.*, 1998; *Meade*, 1985; *Mertes et al.*, 1996; *Dunne et al.*, 1998]. They continue to study and model the supply of sediment to the Amazon from the Andes Range [*Aalto and Dunne*, 1996] and the flow regimes of the entire Amazon River basin with a combination of computer simulation and satellite remote sensing under NASA's Earth Observing System program. For the Paraguay-Paraná River system in South America, we conducted an Environmental Defense Fund review of the hydraulic and sedimentation aspects of the proposed channelization project, Hidrovia. In the Pacific Northwest, Dunne and colleagues have conducted a number of studies of sediment supply and channel change [*Collins and Dunne*, 1990; *Collins and Dunne*, 1989; *Lehre et al.*, 1983]. And in the Oregon Coast Range we have constructed stochastic models of sediment supply and transport, which provide insight into variability in sediment regime [*Benda and Dunne*, 1997a; *Benda and Dunne*, 1997b]. We intend to combine these experiences in field investigation, data analysis, and model development in the Sacramento River basin. The cost will be **$408,409.**

PROJECT DESCRIPTION

We propose to assist CALFED in evaluating proposed restoration strategies such as manipulating flows, sediment supplies, and boundary conditions (e.g. setting back levees) in order to alter the form and hydrologic regime of channels and near-channel wetlands. **We will construct a mathematical model of the channel and floodplain of the mainstem Sacramento River that would provide the predictive capability necessary for analyzing the effects of such restoration strategies.** We will model the manipulable and the uncontrollable influences on the sediment budget and their consequences for habitat restoration.

We will study the Sacramento River and its floodplain as a single unit constructed of interacting reaches in order to quantify basin-scale cumulative response to change. We will quantify the inherent variability in historical empirical data by developing relationships between streamflow, sediment transport, and resultant form of river channels and floodplains along the Sacramento mainstem. These relationships will be used to develop a model of river adjustment processes, which will be validated against new measurements from the Sacramento basin. The model output will describe channel and floodplain morphology resulting from streamflow modification, changes in sediment supply, and channel alteration. It could be applied by land managers to anticipate the morphological outcome of particular restoration strategies and thus, their effect on channel and floodplain habitats spatially over basin and reach scales and temporally over decades.

Geographical Location

The Sacramento River drains the northern part of the Central Valley of California (Figure 1) and has a total drainage area of 6.8×10^4 km^2, comprising over one half of the total drainage area into the San Francisco Bay system [*Porterfield*, 1980]. This study is focused on the Sacramento River Ecological Management Zone [*ERP*, Vol. 2, p. 159 & ERP Figure 8]. The study area includes portions of the following counties: Shasta, Tehama, Glenn, Butte, Colusa, Sutter, Yolo, Sacramento, and Solano. It is applicable to the mainstem Sacramento River and its floodplain south of Shasta Dam in the north to the city of Sacramento in the south. Channel and floodplain dynamics in the tributaries will be excluded from the study, but we will account for their inputs of water and sediment. The Bay-Delta itself will not be studied explicitly though we will determine the long-term rates of sediment delivery to the tidally-affected delta as a result of land-use changes stemming from CALFED management scenarios. The model developed in this research will be extendable to the San Joaquin River and other lowland river systems.

General Approach

We are investigating the processes of morphological adjustment within the Sacramento River basin at various scales of interest. Our aim is to understand these processes on a temporal and spatial scale appropriate for designing restoration strategies (i.e. decades and river reaches, respectively), while maintaining fidelity to the processes of the basin-scale fluvial system. Our approach may be broken down into two distinct tasks: 1) empirical characterization of streamflow, sediment transport, and resultant channel and floodplain morphology and 2) development of a sediment routing model with coupled **basin scale** and **reach-scale** components. The output of the coupled model will predict reach-scale morphological adjustment under different management scenarios and stochastic flow regimes.

Empirical Characterization

Kondolf, et al. (1996) recommend that design of channel modification projects be based on "sound understanding of the site's larger geomorphic context, which requires a historical geomorphic study, and analysis of potential sediment transport at a site." We will reconstruct morphological change on the Sacramento River by evaluating the sediment budget over the last 50 years and comparing the results with the past and current morphological condition of the river, as well as with other regional empirical studies on the Sacramento [*Brice*, 1977; *Buer*, 1994; *Clements*, 1979; *Harvey et al.*, 1988; *Jones et al.*, 1972; *USACE*, 1983]. Quantifying sediment supply within a river system requires construction of a sediment budget or a mass balance of sediment, which will enable land managers to anticipate long-term localities of sediment deposition, storage residence times, and modes of re-mobilization [*Reid and Dunne*, 1996]. A sediment budget involves accounting for all major sediment sources, storage sites, and sinks within a river basin, all of which can vary in time and space. For the case of a large alluvial river, it accounts for rates and processes of erosion and sediment transport within the river and its floodplain. Although sediment budgets have been more commonly applied in small river basins, there have been approximations for large basins that highlight important areas and processes of bank erosion or deposition in the system of sediment transport [*Dunne et al.*, 1998; *Kesel et al.*, 1992; *Reid and Dunne*, 1996].

We have already begun to improve on a previous sediment budget study [*USACE*, 1983] by extending the statistical analysis of sediment transport records (USGS) to calculate long-term average sediment discharge rates into the Sacramento River from its tributaries, as well as rates of sediment discharge through mainstem reaches. In accounting for variability inherent in the fluvial system, a time series analysis approach will be employed to quantify the relationships between streamflow and sediment flux for each gauging station (i.e. those of tributaries near their confluence with the Sacramento and those on the mainstem itself). A time series approach has been advocated [*Fitzgerald and Karlinger*, 1983; *Goodwin and Denton*, 1991; *Lemke*, 1991; *Rodriguez-Iturbe and Nordin*, 1968; *Sharma et al.*, 1979] as an improved statistical methodology that addresses many of the inadequacies of commonly used sediment rating curves [*Ferguson*, 1986; *Heidel*, 1956; *Walling*, 1977]. Time-series transfer functions are superior for describing the relationship between these variables, because they regard time as the crucial domain variable over which hydrologic and sediment variables are serially cross-correlated.

The time-series approach will proceed as follows. The Sacramento basin will be divided into four geologic units (Figure 1) with different sediment/water discharge relationships due to distinct geological substrate properties. Within each geologic unit one gauging station will be designated as a "signature" station, or one that best represents the sediment discharge response to stream discharge over the long term (i.e. usually the station with the longest record for both variables). A transfer function that describes the correlation of the two variables over time will be estimated for each "signature" station (a total of 4, corresponding to the 4 geologic units). The Box-Jenkins transfer function will be employed in a common structure [*Vandaele*, 1983]. Assuming that the sediment record at the "signature" station has captured the range of variability in the sediment signal over the long term, sediment discharge will be estimated for the length of the hydrologic record. This same transfer function will then be applied to the hydrologic record of each remaining gauging station within a geologic unit to 1) validate its utility as a predictor of sediment discharge based on stream discharge and 2) to extend historically short sediment records over the domain of the hydrologic record. For example, a transfer function for a "signature" station with 50 years of hydrologic data and 20 years of sediment data may be used to extend its own sediment record from 20 years to 50 years, and that of a separate station within the same geologic unit from 3 years to 50 years (assuming that hydrologic data exists for 50 years at this latter station). Using this method, long-term average sediment discharge from tributary basins can be calculated. For a tributary with no hydrologic data record, its nearest neighbor scaled by drainage area will be used to estimate long-term average sediment discharge. The same techniques will be used to calculate long-term average flux of suspended sediment through mainstem Sacramento River reaches. However, the mainstem flux calculations will also include output sediment fluxes (some sampled, some simulated) at water diversion canals which decant suspended sediment out of the Sacramento River.

Having evaluated the suspended sediment component of the mass balance, we will then assess the mainstem bedload transport by using averages of sampled values and subtracting quantities extracted by gravel harvest and dredging (obtained from engineering and mining records). We will also conduct a mainstem field survey of the grain size composition of bed and bank materials and assess the general floodplain topography (Figure 2) using USACE data to obtain model inputs and boundary conditions. We will be able to adjust the time series models and bedload assessments to account for long-term changes in the discharge-concentration relationships stemming from land-use change and channel modifications, respectively. We will combine the results of the suspended sediment budget with the bedload assessments to determine zones of long-term deposition or erosion. We will compare these zones with past and current morphological condition of river reaches using aerial photographs and 2-foot vertical resolution DEMs (USACE). This exercise will: 1) establish relationships between stream discharge and sediment discharge that will serve as supply inputs for sediment routing modeling, 2) provide bedload transport rates, as well as grain sizes of both the bed and banks of the Sacramento River for physical model input, 3) generate testable hypotheses on spatial patterns and processes of erosion and deposition in the mainstem Sacramento, and 4) provide long-term average sediment discharge rates from all tributary sources and resultant morphological form to be used in validating the routing model.

Sediment Routing Model

We will relate the empirical sediment budget results to flow volumes, channel hydraulics, and other controls on the mainstem Sacramento River by assimilating the sediment transport measurements, river profiles, grain size data, roughness characteristics, and hydrologic time series into a physically-based sediment routing model. The model will test the influence of restoration strategies on fluvial processes including bank erosion, overbank flooding and deposition, bar deposition, and flushing of fine sediments. We will improve on past routing modeling efforts by coupling two separate routing components of different spatial scales. The **basin-scale** component will conduct down-valley routing of water and sediment over the entire Sacramento mainstem (within the study area) and will compute changes in sediment storage volume for entire river reaches and contiguous floodplains. This component's output will be fed to the **reach-scale** component, which will distribute volumetric change in sediment across individual river reaches in order to determine resultant morphological change (Figure 3 depicts conceptual routing model). For the **basin-scale** component, we will evaluate and choose the best of a number of total load transport models according to a well-document procedure [*Reid and Dunne*, 1996]. The chosen model will be parameterized with surveyed grain size measurements, river cross-sections, and roughness values (for both channel and floodplain). For the **reach-scale** component, we will utilize a routing model that has the capacity for bank erosion and bar deposition (e.g. FLUVIAL-12). This component will be additionally parameterized with higher resolution cross-sections highlighting, bedforms, bank curvature, and floodplain heterogeneity (Figure 2).

Sediment routing models are sets of equations describing: conservation of mass (water and sediment); conservation of momentum (water); sediment transport; and change in channel width [*Dawdy and Vanoni*, 1986]. Additionally, in the development of such a model for a large lowland alluvial basin, we must account for: 1) the stochastic nature of floods required to transport both bedload and suspended sediments 2) overbank inundation and sediment deposition. To represent the stochastic nature of basin hydrology and to predict future conditions, flood events that drive both model components will be chosen at random from constructed probability distributions of recorded hydrologic events at tributary junctions. Sediment input at each junction will be determined from empirical transfer functions that relate hydrology to sediment fluxes. By utilizing the historical flow record for the Sacramento basin in a Monte Carlo simulation we ensure that modeling results will predict resultant morphology cast in the form of probability distributions, which quantify fluvial system variability. To model overbank flooding and vertical sediment accretion, standard sediment routing models (e.g. HEC-6) must be adapted by including the capacity for overbank deposition of sediments [*Gee et al.*, 1990; *Nicholas and Walling*, 1997].

The entire model will be driven by historical records of flow using older cross-sections and validated against recently-collected morphological data (USACE) before it is employed for prediction. In predictive mode, the model will be driven by a random selection of flood events at each time step. We will adjust model inputs and boundary conditions on the reach-scale to reflect implementation of restoration strategies (i.e. changes in flow, sediment supply, and channel alteration). Multiple model runs over a period of decades will provide probabilistic statements of resultant channel and floodplain morphology at the reach- and basin-scales. For example, the model might predict that setting back levees in a particular reach will have a 60% chance of increasing channel migration over 3 m/yr or a 30% chance of building a bar over 0.5 m/yr in that reach.

The purpose of this modeling effort is to provide a physically sound explanation of empirical measurements and to generalize from the recorded data to a broader range of environmental scenarios. **A mathematical model would allow us to quantify the probable effect of alterations of flow regime, changes in sediment supply, or channel modification on sediment transport processes within particular reaches and within the basin as a whole.** It will allow policymakers to anticipate resultant morphological conditions relevant to habitat restoration and flood control strategies such as restoration of "natural" valley streamflow regimes, gravel feeding below dams, or setback levees [*ERP*, Vol.1, p.42-43].

I-014885

ECOLOGICAL BENEFITS

This century has witnessed numerous examples of river adjustment to anthropogenic perturbations. River adjustment to perturbations such as dams, levees, and mining have serious ecological implications in both aquatic and terrestrial environments. However, there have been no attempts at constructing a scientific model which accurately represents such adjustments over large river basins. Consequently, most assessments of river adjustment are made after the fact and involve anecdotal interpretations (e.g. *Schumm and Winkley*, 1994, "The Variability of Large Alluvial Rivers"). To fill this gap, we will develop a predictive model of river adjustment based on data from the Sacramento River basin in California. The research will help to answer the following questions.

- What does empirical evidence tell us about changes in sediment and hydrologic flux regimes in the past and what were the resulting morphological changes?
- How will restoration measures involving changes in flow modification, changes in sediment supply, and channel alteration affect channel and floodplain morphology?
- How will changes in local channel and floodplain morphology affect the evolution of "restored" valley floors?

Background

Since the discovery of gold in the Sierra Nevada 150 years ago, the Sacramento River valley has been drastically transformed by agriculture and human settlement, and hence, by radical flood control policies intended to ensure the survival of these floodplain activities. After decades of trial-and-error flood-control policy on the part of the state and valley residents, the federal government finally committed itself to a unified basin-scale flood control policy. The policy (still in effect) is based on conveying water and sediment as efficiently as possible through the mainstem Sacramento River, using straightened channels and high levees built upon protected river banks to prevent overbank flooding and bank erosion and therefore, lateral channel migration. To relieve pressure on the channel banks and mitigate flood hazard potential, water is impounded behind dams and pumped into flood bypass channels constructed in existing lowland flood basins. The region is now riddled with dams, levees, dikes, and gravel mining operations, which affect the geomorphic character of the river and its floodplain, consequently affecting fish and wildlife habitat, as well as the ability of the river system to naturally attenuate flood events. Although flood hazards and flood damage may have been reduced as a result of damming, channelization, and bank protection on the Sacramento River, the increased flood control has come at the expense of natural bar and riffle formation, thus disrupting a crucial component of riverine ecosystem habitat (Figure 4) [*ERP*, Vol.1, p. 29-30]. Our river adjustment model will enable land managers to implement restoration strategies aimed at improving such habitat.

Ecological Implications

The Sacramento River provides important spawning, rearing, and migratory habitat to anadromous fish populations including chinook salmon (fall and spring runs), splittail, steelhead, white sturgeon, green sturgeon, striped bass, and American shad [*ERP*, Vol.2, p. 165]. The reduction of bars, riffles, and other morphological features within the river channel has hampered salmon spawning runs and movement of other species by reducing resting habitat for fish on their upstream journey. The in-channel ecosystem has been further disrupted by the elimination of upstream and bank erosion sediment sources, thereby preventing replenishment of gravels vital for spawning [*Buer*, 1985; *Reeves and Roelofs*, 1982]. Additionally impoundments dampen flood peaks preventing flushing flows necessary for removing fine accumulations of sediment from spawning gravels [*Milhous*, 1998]. Channelization has also resulted in the loss of side-channel habitat required by more sedentary species and wintering salmon (as well as a loss of terrestrial riparian vegetation and the species it supports) (Figure 4). The Central Valley Project Improvement Act (CVPIA) and its Anadramous Fish Restoration Program (AFRP) call for restoring fish habitats and eliminating stressors by implementing strategies including alteration of flow and sediment supplies, and physical modification of river channels [*Kondolf et al.*, 1996]. Furthermore, one of the fundamental Strategic Ecosystem Goals of CALFED is to rehabilitate natural process in the Bay-Delta system [*ERP*, Vol. 1, p.1]. Such a restorative effort requires a system-wide view of the river's channel and floodplain morphology and the processes involved in shaping it over a time scale of decades.

System-Wide View

The morphology of a river is determined by the interaction of water and sediment within as it flows within a channel network. The river deposits and re-mobilizes the sediment along its valley floor. Where the river lies entirely within its own mobile alluvium, it is classified as an alluvial river, and often obeys certain regularities of form and behavior that allow morphological prediction [*Leopold et al.*, 1964; *Schumm*, 1977]. Fluvial landforms contain information on the depositional and erosional activities of the river, as it continually adjusts to the variable amounts of water and sediment that enter its channel network. It is the spatial and temporal variability of these landforms through the fluvial system which determines the potential flood conveyance capacity, stability of natural and engineered river courses, and the complexity of river channel and riparian habitat [*Dunne*, 1988; *Kondolf*, 1995a; *Kondolf*, 1995b; *Kondolf and Wolman*, 1993]. These landforms determine riverine habitat as the fluvial system adjusts to restoration strategies involving major system alterations [*ERP*, Vol. 1, p. 6].

The fluvial system can be divided into three distinct zones: the production zone, the transport zone, and the deposition zone [*Schumm*, 1977], each of which functions differently in terms of its net transport of materials and thus, its erosional and depositional processes. All zones in the fluvial system are linked. That is, deposition or erosion in one reach of a fluvial zone will affect transport in adjacent zones both upstream and downstream. These adjacent reaches will in turn, affect material transport in their adjacent reaches, and even far downstream. It is apparent that research on material transport processes on the scale of one particular reach cannot represent the fluvial system as a whole, because it does not evaluate feedbacks in material transport between river reaches, including effects far downstream. This spatial variability of transport must be considered along with the temporal variability associated with lags between peaks in flow and sediment transport [*Lemke*, 1991; *Marcus*, 1989] and floodplain storage and remobilization [*Dietrich*, 1982; *Dunne et al.*, 1998]. Restoration strategies must be designed to cope with the dynamic nature of hydrologic and geomorphic processes [*ERP*, Vol.1, p.5]. A basin-scale study of spatial and temporal regime variability will foster a process-based understanding of material transport and resultant morphology within the fluvial system.

Regime Variability

Several major variables govern the spatial and temporal variability of alluvial river morphology and behavior [*Schumm and Winkley*, 1994]. The most important of these are the coupled variables of streamflow and sediment discharge, which depend on drainage basin characteristics and land-use. Sediment supply to an alluvial river is driven stochastically by rainstorms, which affect streamflow, sediment transport and thus, the intensity of erosional and depositional activities within a river system [*Benda and Dunne*, 1997b; *Schumm*, 1977]. There have been recent efforts to characterize the dynamic sediment regime of a river system in terms of its statistical properties. This is accomplished by computing the probability of the transport system being in any of various states [*Benda and Dunne*, 1997a] based on historical changes in observed sediment transport data [*Lemke*, 1991]. Such a characterization would allow one to design restoration strategies that represent the fluctuations in the transport system over time [*ERP*, Vol.1, p.50] or that allow prediction of the temporal and spatial variability of current and restored habitat. Our modeling approach uses time series analysis and Monte Carlo simulation in order to take into account the variability and memory of a fluvial system [*Knighton*, 1984] as it continually adjusts to controls.

Adjustment to Controls

Throughout the fluvial system there are constraints, or controls, on material transport, which result in some level of morphologic adjustment on the part of the river system. Such controls, or perturbations, are either natural (e.g. tectonic, climatic) or anthropogenic (e.g. dams, levees, channel re-alignment, gravel mining). As new perturbations are imposed, adjustments are made by the fluvial system, which can radically change a river's planform and cross-section. However, there has been no research effort at creating a reach-integrated, basin-wide view of morphologic adjustment. The breadth of such a perspective could facilitate the planning of restoration efforts in river systems in the context of widely acknowledged, but rarely quantified, basin-scale cumulative effects.

Flood control planning and ecosystem rehabilitation both need to be based on understanding of the history of river channel change and therefore of material flux regimes [*ERP*, Vol. 1, p. 79]. River channel change results from a set of erosional and depositional processes by which a river adjusts to perturbations. For example, when dams are installed, a river system goes through a complex process of adjustment [*Schumm*, 1981; *Williams and Wolman*, 1984; *Xu*, 1990] to changes in supply of water and sediment. Morphological adjustments to reservoirs are typified by backwater effects and sediment deposition upstream of the dam and by scour of bed material downstream [*Chien*, 1985]. Mining within river basins also contributes to complex responses in river systems. This can occur as a result of extra-valley-floor mining, wherein sediment delivery from hillslope sources causes river width-depth ratios to increase as the system shifts from supply limited to transport limited [*Gilbert*, 1917; *James*, 1991; *Knighton*, 1989]. It an also occur as intra-valley floor mining, where extraction of riverbed or floodplain sediment can cause bed elevations and width-depth ratios to decrease [*Collins and Dunne*, 1989, 1990], and can cause channel migration as flow is deflected from in-stream gravel pits [*Dunne and Leopold*, 1978]. Channelization, or channel dredging and straightening for navigation or flood control, has effects similar to those of intra-valley floor mining with the added tendency for acceleration of bank erosion and meandering [*Neill and Yaremko*, 1988] and piping of levees and dikes [*Feldman*, 1973; *Laddish*, 1997; *Olson et al.*, 1942; *Schalk and Jacobson*, 1997].

In all these cases morphological adjustments have been described by their resultant form characteristics of cross-sectional channel geometry [*Gregory and Park*, 1974; *Xu*, 1996], bed material sizes [*Williams and Wolman*, 1984], and longitudinal profile [*Chien*, 1985]. However, in the context of complex river response to perturbations [*ERP*, Vol.1, p. 13-14], attempts to explain the physical processes associated with adjustments have relied upon qualitative assessments [*Xu*, 1990], thus preventing their accurate application in other localities with different spatial and temporal scales of material flux and levels of disturbance. To provide a foundation for riverine ecosystem rehabilitation, we will construct a process model of basin- and reach-scale channel and floodplain morphological adjustment that is based on assimilation of excellent historical empirical datasets collected within the Sacramento River basin. In constructing our process model by assimilating data from various sources, we will build upon the information which could be gleaned from any particular dataset.

Employing this multi-scale, integrated modeling approach will provide understanding of the process of river adjustment in the context of valley-floor evolution at the basin-scale and of morphological change pertaining to habitat considerations on the reach-scale. The model will complement on-going studies of sediment dynamics in the Bay-Delta [*Dinehart*, pers. comm] and of channel shifting in the lower Sacramento [*Larsen*, pers. comm]. It will yield probabilistic statements of morphological channel-floodplain adjustment to regime variability and perturbations over a period of decades. This knowledge would be useful not only in the restoration of large river basins, but in aiding design of new river development projects. By addressing the problems of the Sacramento Bay-Delta with an integrated, comprehensive approach of this kind the CALFED Bay-Delta Program could set the international standard for restoration of large lowland river systems.

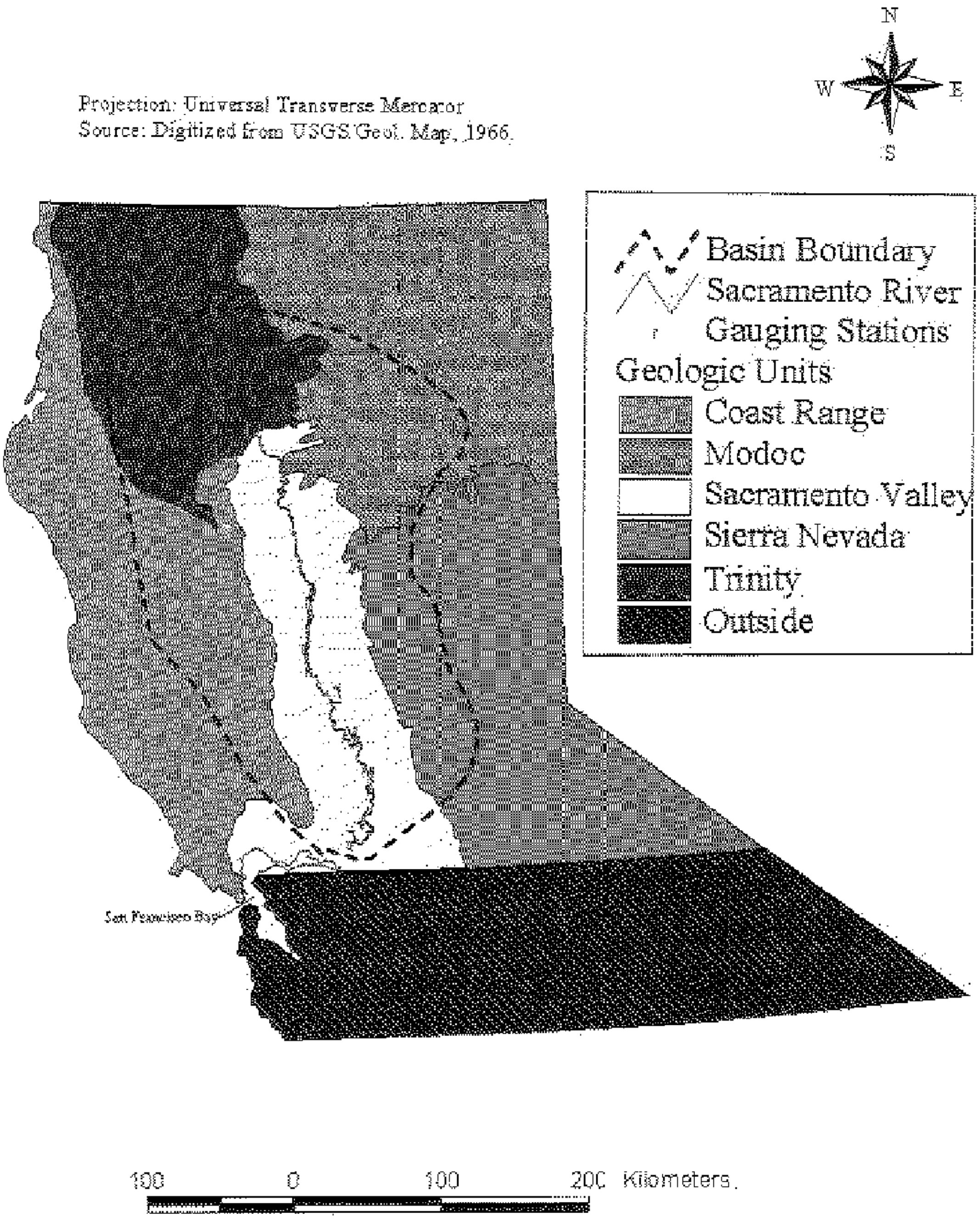

Figure 1. Map shows approximate boundaries of Sacramento River basin and its geologic units from which sediment is derived. "Outside" refers to area outside the study basin.

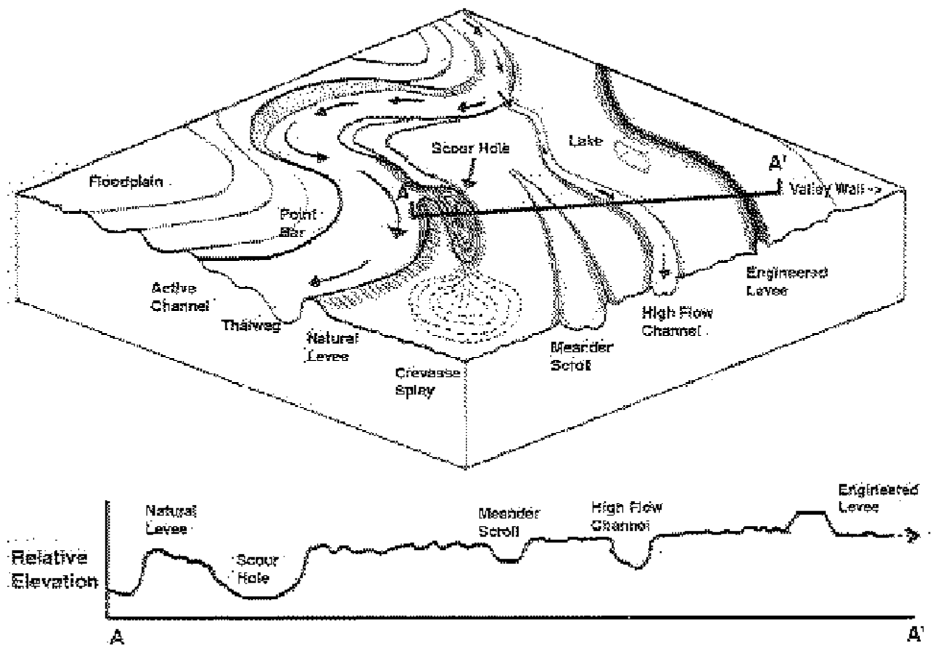

Figure 2. Schematic showing floodplain variability that will be represented in reach-scale model cross-sections.

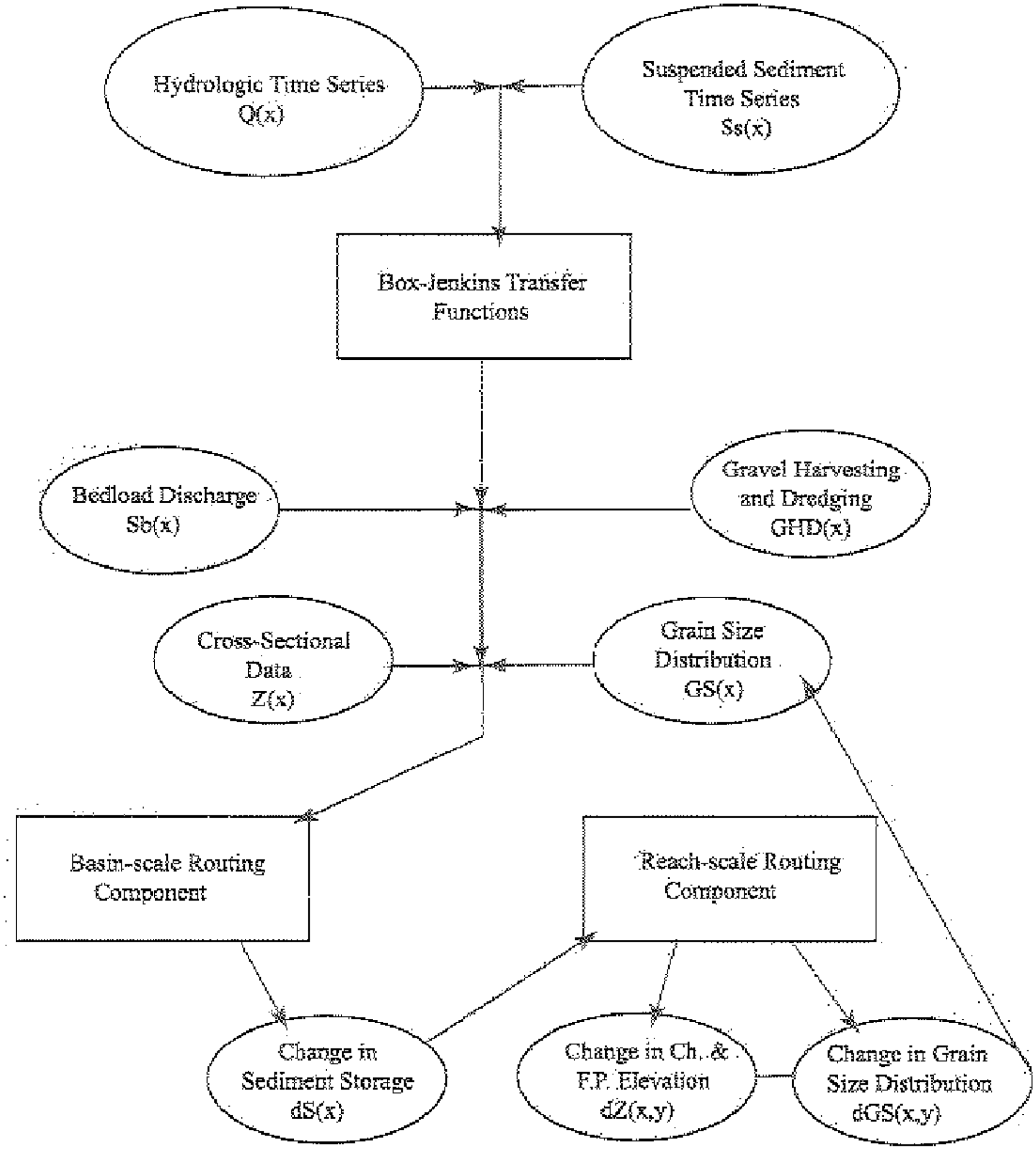

Figure 3. Conceptual sediment routing model (roughness inputs not shown).

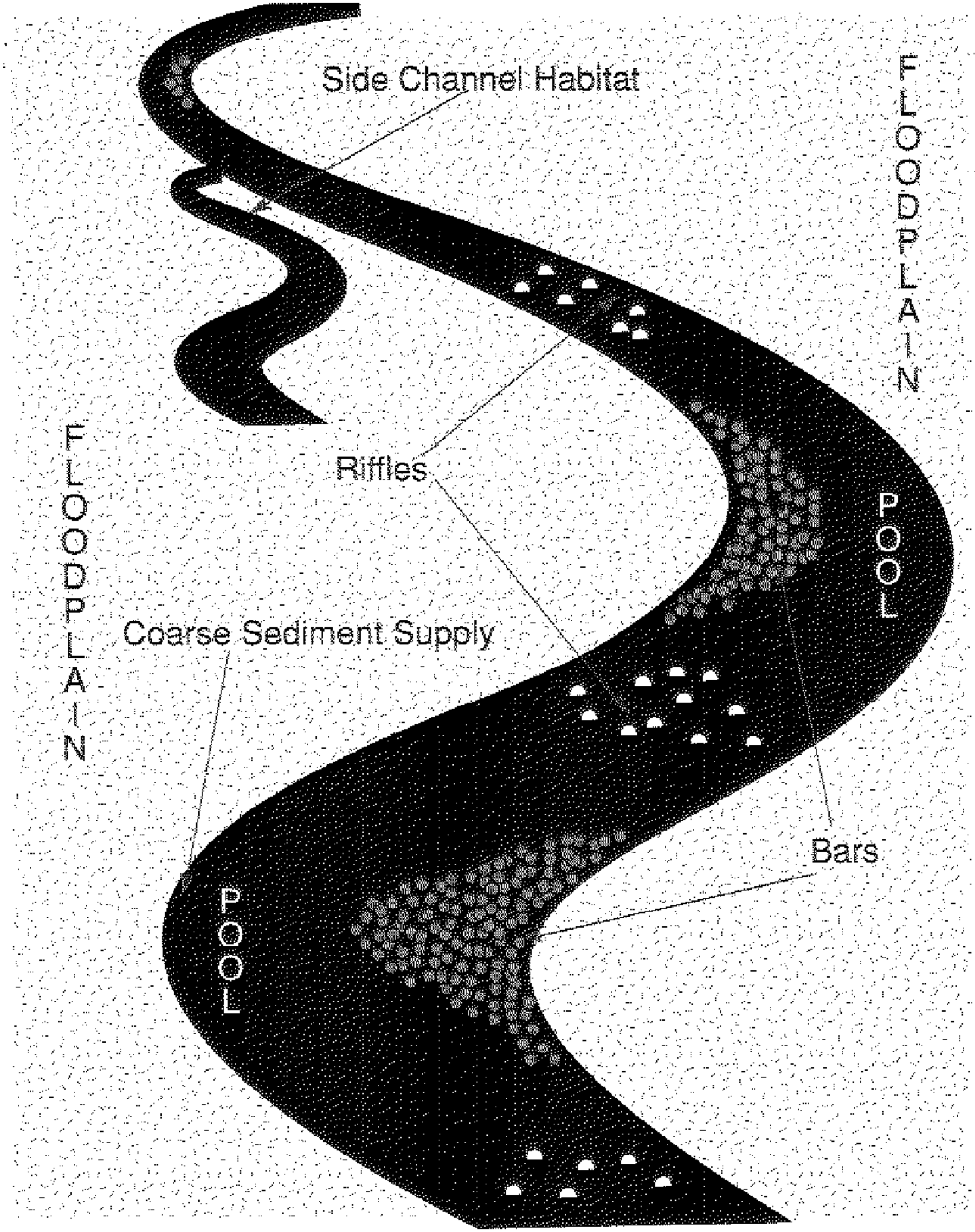

Figure 4. Schematic showing crucial morphological components of riverine ecosystem habitat.

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TECHNICAL FEASIBILITY AND TIMING

We already possess much of the equipment with which to complete this project. Our laboratory at UCSB is equipped with high speed NT PCs, a UNIX workstation, Arc/INFO and other necessary software, a digitizer, a Total Station, and a Differential Global Positioning System (GPS). The three-year budget requests support for one Graduate Student Researcher, one laboratory assistant, purchase of aerial photos, a laptop computer for field use with our GPS, a digital camera for documenting river reaches digitally, a data storage disk for the high volume of necessary data, an auger, a river bottom sediment sampler, engineering software, and field travel expenses.

The project will be conducted in two phases: I) the empirical characterization phase and II) the modeling phase. Phase I will be conducted over the first year of the funding period. The primary tasks during this phase are data acquisition and empirical basin characterization. Subtasks include: collection of field ground control points with GPS; registration and rectification of aerial photographs; digitization of historical Sacramento maps; grain size data collection, floodplain topographical characterization, development of time series transfer functions, and correlation of historical hydrological and sediment data with morphological change in the basin.

Phase II will be conducted during the second and third years of the funding period. The primary task is developing a coupled multi-scale sediment routing model. Subtasks include: constructing a probability distribution of flood events; numerical modeling of total load sediment transport at both scales; model validation using new river profiles; and field verification of modeling results.

We will travel Romania this summer to visit CALFED's European counterpart, the Romanian government's Danube Delta Biosphere Reserve, in order to gain insight from its ongoing restoration experience. The Danube project has begun restoration activities by breaching levees and dikes, thus providing a field laboratory for studying morphological change associated with land-use change. By visiting Danube restoration sites we will witness processes too complex to be modeled, as well as the unintended consequences of such a restoration effort on a spatial scale relevant to CALFED. We have long-established contacts with geomorphologists who study large tributaries of the Danube.

In addition to official CALFED symposia, we will publicize our research effort annually at the Fall Meeting of the American Geophysical Union and other relevant regional and international conferences.

DATA COLLECTION

For this study we are compiling an excellent dataset for a large river basin study. In addition to streamflow and sediment concentration records, bedload data, topographic and other maps for the Sacramento basin (USGS), we have been locating and collecting: engineering records; cross-sectional geometrical surveys; aerial photographic coverage of the Sacramento basin from the 1920's to the present; two foot vertical resolution Digital Elevation Models (DEMs) of channel and contiguous floodplain (USACE); special-mission NASA air photos documenting 1997 flooding; data on California storm magnitudes and intensity from NOAA.

The long-term average suspended sediment load will be calculated using flow data and suspended sediment samples (USGS) historically and presently collected. The suspended sediment data will be used in conjunction with flow data to estimate time series transfer functions. The bedload component of the Sacramento River sediment budget will be calculated using measured bedload transport values (USGS) and subtracting the fraction extracted by gravel mining and dredging per unit time (calculated from industry data). Information on the sand-silt division in suspended sediment will be extracted from USGS records and used for model input. We will conduct boat surveys on the mainstem (from Sacramento to Shasta Dam) of grain size distributions of each sediment storage reservoir (i.e. the bed and banks) on a reach-by-reach basis. We will collect bed samples with a grab sampler. Bank conditions will be recorded by digital camera and by auger, georeferenced by GPS, and stored in a digital database. Texture of bank sediment samples will be documented by sieving and hydrometry. Floodplain topography (Figure 2) required for overbank sediment routing will also be assessed using a combination of field survey and DEMs from the USACE.

LOCAL INVOLVEMENT

As suggested in the Executive Summary we have confirmed that our proposed study is complementary to ongoing work and research in the Bay-Delta. We have been communicating with researchers and agency personnel who are currently working on the Sacramento River. We have made contact with Randall Dinehart (USGS) and Jeff Harris (USACE), each of whom currently have studies under way on the Sacramento River. We have also been conversing with Eric Larsen (UC Davis) who is engaged on a channel shifting study in the lower Sacramento. We have also been collaborating with Jeff Harris (USACE) and Larry Smith (CALFED-USGS) to obtain new and historical Sacramento River data in order to build a model that utilizes the latest technology and that will be compatible with USACE and USGS priorities.

I-014899

OMB Approval No. 0348-0044

BUDGET INFORMATION - Non-Construction Programs

SECTION A - BUDGET SUMMARY

Grant Program Funtion or Activity (a)	Catalog of Federal Domestic Assistance Number (b)	Estimated Unobligated Funds		New or Revised Budget		
		Federal (c)	Non-Federal (d)	Federal (e)	Non-Federal (f)	Total (g)
1 CALFED Bay-Delta Program	15-614			128,848		
2						
3						
4						
5 Totals		$	$	128,848	$	$

SECTION B - BUDGET CATEGORIES

6. Object Class Categories	GRANT PROGRAM, FUNCTION OR ACTIVITY				Total (5)
	(1)CALFed Bay Delta Program	(2)	(3)	(4)	
a. Personnel	58,906				
b. Fringe Benefits	10,932				
c. Travel	12,700				
d. Equipment	4,700				
e. Supplies	3,250				
f. Contractual					
g. Contstruction					
h. Other	800				
i Total Direct Charges (sum of 6a-6h)	91,288				
j. Indirect Charges	37,560				
k. TOTALS (sum of 6i and 6j)	128,848	$	$	$	$
7. Program Income	$	$	$	$	$

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SECTION C - NON FEDERAL RESOURCES				
(a) Grant Program	(b) Applicant	(c) State	(d) Other Sources	(e) TOTALS
8	$	$	$	$
9				
10				
11				
12. TOTAL (sum of lines 8 - 11)	$	$	$	$

SECTION D - FORCASTED CASH NEEDS					
	Total for 1st Year	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
13. Federal	$128,849	$24,861	20,162	22,427	61,399
14. Non Federal					
15. TOTAL (sum of lines 13 and 14)					

SECTION E - BUDGET ESTIMATES OF FEDERAL FUNDS NEEDED FOR BALANCE OF THE PROJECT				
(a) Grant Program	(b) First	(c) Second	(d) Third	(e) Fourth
16. CALFED Bay Delta Program	$144,222	135,339		
17				
18				
19				
20. TOTAL (sum of lines 16-19)				

SECTION F - OTHER BUDGET INFORMATION	
21. Direct Charges: $122,531	22. Indirect Charges: 46% (provisional) Base Sum: $266,373
23. Remarks:	

CALFED Bay-Delta Program
Thomas Dunne
University of California, Santa Barbara
Donald Bren School of Environmental Science & Management

DETAILED BUDGET					First Year 10/1/99-9/30/00	Second Year 10/1/00 9/30/01	Third Year 10/1/01 9/30/02	Total 10/1/99 9/30/02
SALARIES		Period/mos.	% Time					
1. Principal Investigator - Thomas Dunne								
Professor of Environmental Science & Management								
a. Summer months @ 1/9 annual rate of								
$144,097 1st yr.		1	100%	$	16,011			16,011
$151,302 2nd yr.		1	100%			16,811		16,811
$158,867 3rd yr.		1	100%				17,652	17,652
b. Academic period		9	5%		0	0	0	0
2. Graduate Student Researcher - III - Michael Singer								
@ III	$2,801 /mo. 1st yr. academic	9	49%	$	12,352			12,352
@ III	$2,801 /mo. 1st yr. summer	3	100%		8,403			8,403
@ IV	$3,086 /mo. 2nd yr. academic	9	75%			20,831		20,831
@ IV	$3,086 /mo. 2nd yr. summer	3	100%			9,258		9,258
@ IV	$3.148 /mo. 3rd yr. academic	9	75%				21,249	21,249
@ IV	$3.148 /mo. 3rd yr. summer	3	100%				9,444	9,444
3. Lab Assistant I - TBD								
@	$1,845 /mo. 1st yr.	12	100%	$	22,140			22,140
@	$1,882 /mo. 2nd yr.	12	100%			22,584		22,584
@	$1,920 /mo. 3rd yr.	12	100%				23,040	23,040
		Total Salaries			58,906	69,484	71,385	199,775
FRINGE BENEFITS								
1. Principal Investigator - Thomas Dunne								
Base Sum	$16,011 1st yr.	3.00%		$	480			480
	$16,811 2nd yr.	3.00%				504		504
	$17,652 3rd yr.	3.00%					530	530
2. Graduate Student Rsearcher - Michael Singer								
Base Sum	$12,352 1st yr.	1.40% (academic)		$	173			173
	$8,403 1st yr.	3.00% (summer)			252			252
	$20,831 1st yr.	1.40% (academic)				292		292
	$9,258 2nd yr.	3.00% (summer)				278		278
	$21,249 2nd yr.	1.40% (academic)					297	297
	$9,444 2nd yr.	3.00% (summer)					283	283
FRINGE BENEFITS (cont'd)								
3. Lab Assistant I - TBD								
Base Sum	$22,140 1st yr.	23.00%			5,092			5,092
	$22,584 1st yr.	23.00%				5,194		5,194
	$23,040 1st yr.	23.00%					5,299	5,299
3. Graduate Student Health Insurance*					813	813	813	2,439
4. Graduate Student Fees (in-state)					4,122	4,122	4,122	12,366
		Benefits Subtotal		$	10,932	11,203	11,344	33,479

EQUIPMENT					
1. Laptop Computer		$ 3,500	0	0	3,500
2. Digital Camera		600	0	0	600
3. 9 GB Hard Disk		600	0	0	600
	Equipment Subtotal $	4,700	0	0	4,700
FIELD SUPPLIES					
1. Airphotos, 200 @ $10.00 each		$ 2,000	0	0	2,000
2. Auger		300	0	0	300
3. Grab Sediment Sampler		950	0	0	950
	Supplies Subtotal $	3,250	0	0	3,250
TRAVEL (increasing 5% per year)					
1. Field Campaign - 2 weeks boat rental @ $250/ day years 1 and 2, 40 days car rental @ $30/ day, per diem $100/ day 40 days, per year. 2 people		$ 12,700	13,335	10,143	36,178
	Travel Subtotal $	12,700	13,335	10,143	36,178
PUBLICATION COSTS (increasing 5% annually)		$ 500	1,000	1,050	2,550
OTHER DIRECT COSTS (increases @ 5%/yr)					
1. Long-distance phone, photocopying, fax and project mailin[g]		$ 300	315	331	946
2. MicroStation SE software			2,500		2,500
3. Inroads software			2,500		2,500
	$	300	5,315	331	5,946
	Total Direct Costs $	91,288	100,337	94,253	285,878

INDIRECT COSTS

On-campus rate** of Modified Total Direct Costs							
Base Sum:	81,653	46.00% 1st yr.		$ 37,560			37,560
	95,402	46.00% 2nd yr.			43,885		43,885
	89,318	46.00% 3rd yr.				41,086	41,086
	266,373		Total Indirect Costs $	37,560	43,885	41,086	122,531
			TOTAL COSTS	128,848	144,222	135,339	408,409
			TOTAL COST THREE YEARS $	**408,409**			

* Supplied to all Teaching assistances and Graduate Student researchers employed at 25% time or more

** This is the DHHS negotiated, predetermined, on-campus indirect cost rate for the period 7/1/97 through 6/30/00. The rate thereafter is provisional.
Modified Total Direct Costs includes total direct costs less Graduate Student Health Plar Graduate Students Fees and equipment

THOMAS DUNNE: CURRICULUM VITAE

Professor, Donald Bren School of Environmental Science and Management, and Department of Geological Sciences, 4670 Physical Sciences North, University of California, Santa Barbara, CA 93106

EDUCATION B.A. 1964 Cambridge Univ., UK; Ph.D. 1969 Johns Hopkins University, (Geography)

HONORS Fulbright Scholar, 1964; Robert E. Horton Award, American Geophysical Union, 1987; National Academy of Sciences, 1988; Fellow, American Geophysical Union, 1989; Guggenheim Fellowship, 1989; American Academy of Arts and Sciences, 1993; Fellow, California Academy of Sciences, 1996; National Research Council Wolman Distinguished Lecturer, 1997; National Academy of Sciences Warren Prize for Fluviatile Geology, 1998.

CURRENT RESEARCH INTERESTS

Hydrology, sediment transport, and sedimentation in valley floors

Field studies and modeling of river-basin sediment budgets.

Field and theoretical studies of drainage basin and hillslope evolution

PUBLICATIONS (last 5 years)

T. Dunne, K. X Whipple, and B.F. Aubry, Microtopography of hillslopes and the initiation of channels by Horton overland flow, In: **Evolving Concepts in Fluvial Geomorphology** (ed. J.E. Costa), American Geophysical Union, Geophysical Monograph, 1995.

L.A.K. Mertes, T.Dunne, and L.A Martinelli, Channel-floodplain geomorphology along the Solimões-Amazon River, Brazil, **Geological Society of America Bulletin**, 108, 1089-1107, 1996.

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T. Dunne, Hydrologic science.... on a planet... in landscapes... in the future, In **Hydrologic Science: Taking Stock and Looking Forward**, National Academy Press, Washington DC, pp. 10-43,1998.

T. Dunne, Critical data requirements for prediction of erosion and sedimentation in mountain drainage basins, **Jour. American Water Resources Association**, 34, 795-808, 1998.

Elsenbeer, H., B. E. Newton, J. M. de Moraes, and T. Dunne, A survey of soil hydraulic properties and their implications for runoff generation under different vegetation covers in Rondônia, Brazil, **Hydrologic Processes, 1999.**

OTHER RELEVANT PUBLICATIONS

T. Dunne and L. B. Leopold, **Water in Environmental Planning,** W. H. Freeman Co., San Francisco, 818 pp., 1978.

W. E. Dietrich, J. D. Smith, and T. Dunne, Flow and sediment transport in a sandbedded meander, **Journal of Geology**, 87, 305-315, 1979.

W. E. Dietrich, T. Dunne, N. F. Humphrey and L. M. Reid, Construction of sediment budgets for drainage basins, **Sediment Budgets and Routing in Forested Drainage Basins**, U.S. Forest Service General Technical Report PNW-141, Pacific Northwest Forest and Range Expt. Sta., 5-23, 1982.

W. E. Dietrich, J. D. Smith, and T. Dunne, Boundary shear stress, sediment transport, and bed morphology in a sand-bedded meander during high and low flow. In: **River Meandering**, Amer. Soc. Civil Engineers, 632-639, 1984.

R. H. Meade, T. Dunne, et al., Storage and remobilization of suspended sediment in the Lower Amazon River of Brazil, **Science**, 228, 488-490, 1985.

T. Dunne, Geomorphological contributions to flood-control planning; In **Flood Geomorphology** (Eds. V. R. Baker, R. C. Kochel, and P. C. Patton), Wiley & Sons, NY, 421-438, 1988.

B. D. Collins and T. Dunne, Gravel transport, gravel harvesting, and channel-bed degradation in rivers draining the Southern Olympic Mountains, Washington, USA, **Environmental Geology and Water Science**, 13, 213-224, 1989.

J. E. Richey, L. A. K. Mertes, T. Dunne, and five others!, Sources and routing of the Amazon River floodwave; **Global Biogeochemical Cycles**, 3, 191-204, 1989.

B. D. Collins and T. Dunne, **Fluvial Geomorphology and River-gravel Mining**, Spec. Pub. 98, Division of Mines and Geology, California Department of Conservation, 29 p., 1990.

COMMITTEE REPORTS

Alluvial fan flooding: definition and criteria, U.S. National Research Council, (with other members of the Committee on Alluvial Fan Flooding, 1996.

The Hidrovía Paraguay-Paraná Navigation Project: Report of an Independent Review, by T. Dunne, J. Melack, B. Melia, J. Paggi, S. J. Paggi, T. Panayotou, H. Rattner, E. Salati, I. Klabin, T. Scudder, and M. Clemens, Environmental defense Fund, Washington, DC, 214 p., 1997.

Thomas Dunne is a Professor of Environmental Science and Management, and of Geological Sciences at the University of California Santa Barbara. He conducts field and theoretical studies of drainage-basin, hillslope, and fluvial geomorphology, and in the application of hydrology and geomorphology to landscape management and hazard analysis.

While working for the USDA Agricultural Research Service (1966-1969) and McGill University (1971-1973), he conducted research on the effects of topography, soil characteristics, and vegetation on runoff processes under rainfall and snowmelt in Vermont and Canada. While teaching at the University of Nairobi (1969-1971), he initiated a long-running research interest in African environments, including experimental studies of runoff and erosion processes, and statistical studies and field surveys of the effects of land use on hillslope erosion and river-basin sediment yields. He also conducted occasional studies of reservoir sedimentation, water quality, and erosion due to charcoal production and grazing. This work, between 1969 and 1991, was supported by foundations, the United Nations, US and Kenya agencies.

While teaching in the Department of Geological Sciences at the University of Washington (1973-1995), he studied landsliding and debris flows; drainage-basin sediment budgets in natural and managed forests; tephra erosion and debris-flow sedimentation on active volcanoes; and sediment transport and channel morphology in sand-bed and gravel-bed river channels. He also conducted several studies related to resource management, such as the impacts of gravel harvesting on the river-channel sedimentation and morphology; impacts of timber harvest on erosion and sedimentation; and effects of flow diversion and reservoir management on sedimentation.

He now leads an Interdisciplinary Science Team, participating in the NASA Earth Observing System, that studies hydrology, sedimentation, biogeochemistry, and environmental change in the Amazon River Basin of lowland Brazil and the Andes Range of Bolivia. The work has been funded by NASA, NSF, and the US Geological Survey. His particular scientific role in the project involves: field measurements of soil properties, runoff and erosion processes on hillslope scales; sediment transport and floodplain sedimentation, and modeling of streamflow and sedimentation throughout the whole basin employing data from ground networks and satellites.

He has gained experience of geomorphic and hydrologic processes related to development projects through research and consultancies in many parts of the world, and has expressed some of that experience in teaching courses, advising government agencies, writing papers, and co-authoring two textbooks.